Convection Processes in the Ocean-Laboratory and Theoretical Studies

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LONG-TERM GOAL

My long-term goal is to make observations in the laboratory and conduct associated theory of nonlinear fluid dynamics important in the ocean.

OBJECTIVES

Two processes were studied recently. The first is the behavior of convective flow driven by two distinct buoyancy sources, in which more than one flow pattern is found for exactly the same forcing conditions. A primary objective was to determine the quantitative role of mixing upon circulation. The second is the strength and size of flows from sidewall forcing in rotating stratified fluid. The primary objective was to document the flow patterns near a line source of heat located at mid depth on the periphery of a cylinder in a rotating stratified fluid. Both are poorly understood but known to be important in assorted oceanic phenomena.

APPROACH

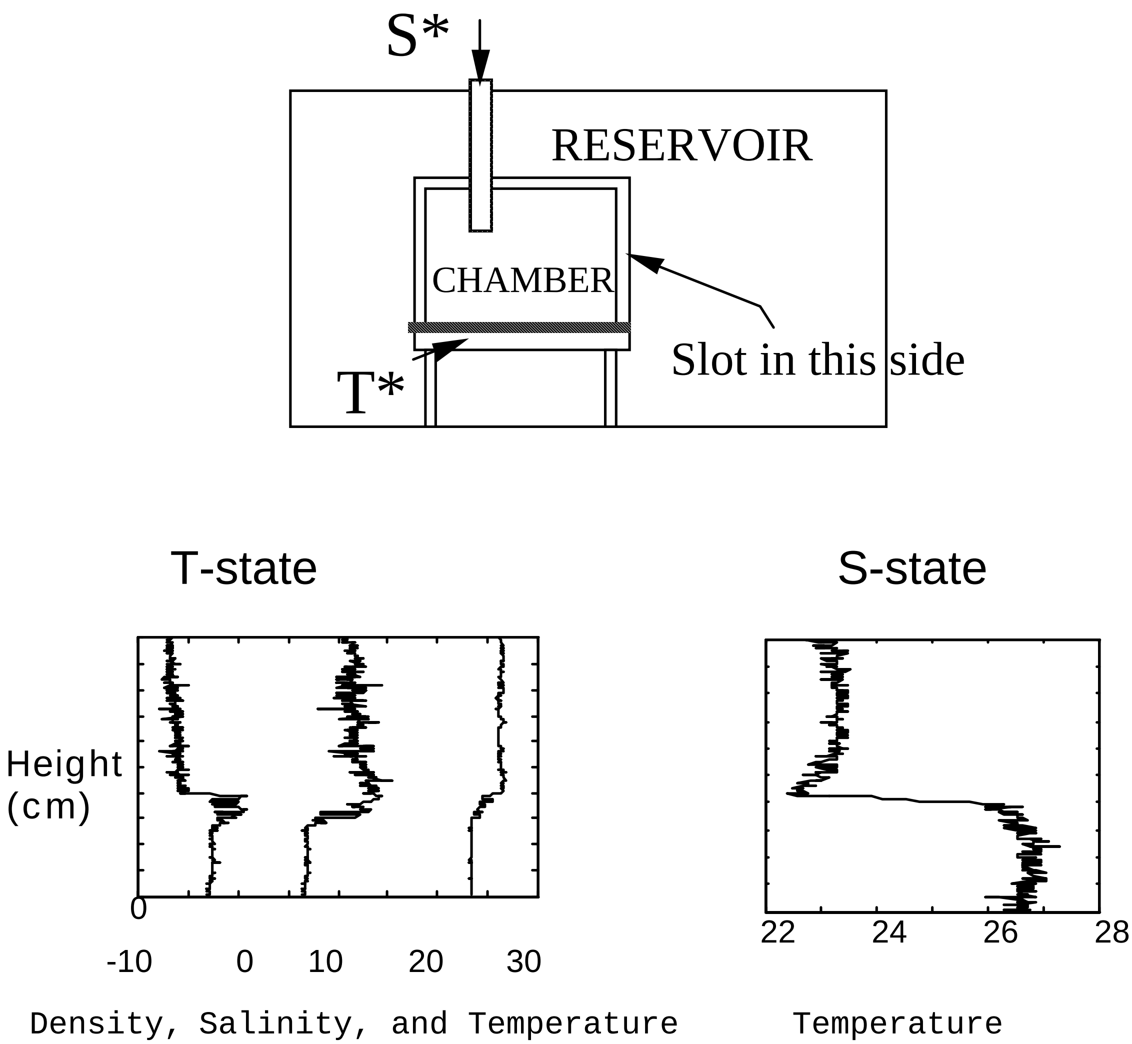
First we developed prototype laboratory experiments and generated simple theories. The experiments and theories indicated the design requirements for further experiments in both problems. We then designed and conducted new laboratory experiments which are completed.

ACCOMPLISHMENTS

In the multiple states problems, most theories to date involve drastic simplifications with either simple box models or frictionally regulated flow. With the ultimate objective of conducting experiments for rotating flows, we have been able to develop a chamber whose floor was heated and which has an inflow of salty water near the top. This chamber was connected to a large tank of room temperature fresh water through a slot. The prototype experiments indicated that mixing within the chamber must be limited for the flows to differ from the simple box models mentioned above. Thus a theory for undermixed exchange flow was developed (theory supported by NSF) and successfully tested. The results were used to design an undermixed doubly driven chamber. Mixing was varied by changing the elevation of a tube which introduces the salty water. For boundary layer processes in rotating stratified fluid, boundary layers produced by heating from the side have been produced in a laboratory cylinder of thermally stratified water on a turntable. The results are compared with calculations by Joseph Pedlosky. A variety of other theoretical solutions have been developed which reveal these boundary layers and their strength in great detail.

SCIENTIFIC/TECHNICAL RESULTS

It is now clear that multiple states can be found in a variety of simple analytical numerical model problems in the general area of GFD. The undermixed doubly driven chamber exhibited a range of multiple states for large mixing, but in contrast to the well mixed box models, the density field in the chamber varied with depth. Figure 1 shows a sketch of the chamber and vertical profiles of the two distinct states which were found for the same values of forcing.



Density units: (Density (in MKS) -998.2)*10
Salinity parts per 10^4
Temperature in deg. C.

Figure 1. Sketch of the experimental chamber which produced multiple states and time dependent flows. Mixing rate was varied by changing the elevation of the tube which brings in fluid of salinity S*. Vertical profiles found in the chamber are shown from experiments in which bath temperature T* and the flow rate of S* were the same. Unfortunately the salinity profile for the S-State was not yet available.

As the tube was set to lower elevation, mixing got smaller and the flows developed pronounced time dependence so the flow in the chamber spontaneously migrated from one state to another via intermediate modes. These are presently being documented.

Boundary layer sizes and the magnitude of flow in laboratory experiments using stratified rotating fluids now exhibit good agreement over a broad range for a variety of boundary forcing. One prominent boundary layer is produced from either vertical or horizontal boundaries and is Rossby Radius times square root of the Prandtl number in size. Thus the strength and size of some boundary layers predicted many years ago are now confirmed by physical measurements. Such structures seem apparent in some ocean observations.

IMPACT FOR SCIENCE OR SYSTEMS APPLICATIONS

For large mixing, the classical box models have been verified. For limited salt mixing, a halocline develops. In some ranges the laboratory experiments possess a "climate" which is continuously fluctuating so that variables effecting density and stratification such as salinity and temperature distribution constantly change. It is clear that water bodies of many sizes, from estuaries to global oceans driven by both haline and thermal forcing could develop unsteady states such that their halocline and/or thermocline may fluctuate spontaneously. Length and velocity scales for rotating stratified linearized flow have now been clearly observed. Such scales may be found in many natural settings where water is subjected to differential temperature and wind forcing. It is unlikely that numerical models would properly resolve these scales since such models use large values of diffusion to remain stable.

TRANSITIONS

The fluctuations of some well-known climate models have now been verified by physical experiment. Work to locate direct observations of catastrophic thermohaline transitions continues. We also seek observations of irregular thermohaline structures in partially mixed regions. Some of the boundary layers seen in the rotating stratified experiments may have counterparts in the ocean. Focused oceanographic studies appear to be necessary for confirmation of the boundary layer structures.

RELATED PROJECTS

The findings of many model studies which reveal transitions to time-dependent flow such as Huang, Luyten and Stommel (1992), and Dewar and Huang (1995) agree with the present partially mixed experiments. Arrested Ekman suction which we clearly observed for rotating stratified flow near a bottom (or top) was predicted first by Barcilon and Pedlosky (1967a-c) and more recently by others (MacCready and Rhines 1993, MacCready 1994, Chapman and Lentz 1994, 1997). Experiments upon eddy shedding next to a coast (Cenedese and Whitehead 1998) follow work started in previous years (Stern Chassignet and Whitehead 1996) supported by ONR.

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